Urban thermal and mechanical effects on surface warming and cold front structures over eastern China

論 文 内 容 要 旨

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学位論文の 題　　目	Urban thermal and mechanical effects on surface warming and cold front structures over eastern China （中国東部における地表温度と寒冷前線構造に関する都市の熱的· 力学的効果）		

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Abstract

Urban surface influences local weather and climate through thermal and mechanical effects. Closely related with urban thermal effects, surface temperature is widely investigated through establishing a general connection with city size. By taking other complex aspects of urban growth (e.g. spatial pattern, growth speed) into consideration, this study aims to provide a new and comprehensive evaluation of urbanization effect on local temperature change. Mechanical effects work through transforming flow patterns in urban areas, e.g. active turbulence is observed. More than focusing on turbulence itself in traditional investigations, this study attempts to explore the interaction between urban boundary turbulence and mesoscale weather, which is little understood before. The results would share new implications for local weather forecast.

Using satellite nighttime light for medium and large cities over eastern China, we quantitatively assess the rapid growth of urban areas and investigate its impact on long-term surface warming. Statistic results show that surface warming is closely related with the city size. More than city size, surface temperature increase also exhibits a strong association with urban growth. A rapid increase of surface temperature is observed mainly at cities undergoing

rapid urbanization. On the other hand, a weak warming is reported at cities experiencing slow urban growth. Such a relation between urban growth and surface warming is evident over Central, South, and Northwest China, but it is weak over Northeast China, implying regional variations of temperature responses to urban growth compared with other region-dependent forcings (e.g. climate backgrounds and local features).

Satellite-derived land surface temperature analysis suggests the correspondence between urban growth and urban heat island expansion, which is then reflected by site observations. Cities experiencing rapid urbanization are more subject to the effects of urban heat island expansion, thus report strong warming. Isolated cities, which are far away from the rapid urban growth region, are less affected by the urban heat island expansion, thus experience weak warming. This strong link between temperature trend and rapid urbanization explains the variations of warming rate among cities within the same region.

Mechanical effect of urban surface on flow structures is investigated by an urban-scale super high resolution simulation of a cold front passage over Guangzhou city, China. The flow structures differ dramatically between with-building and without-building experiments. In the presence of buildings, the cold front head moves at different speed thus deforms into an irregular line with bumps and dents at surface. At the top, cold front rises and falls alternatively due to different thermal patterns below it, and forms an undulating 3-dimensional structure. In general, the movement of cold front is slowed down over urban surface. Vertically, the cold front separates into upper and lower parts, with the lower part moving slower than the upper part due to the blocking effects of buildings. As a result, the air near the surface is warmer than its upper counterpart and forms a vertically unstable stratification favorable for turbulence generation. Consequently, active turbulence is identified over urban surface after front passage. The turbulence displays streaky structures and develops along streamwise direction. The streaky turbulence structures are most active above the building roof and have a horizontal scale of hundreds of meters, which is much larger than the building size.

Generation of the turbulence structures after front passage is closely related with the presence of buildings. Rising motion is formed behind buildings and developed along the downstream direction as a result of the warm air remaining after front passage. Sinking motion is then developed at neighboring areas as a compensation. With increasing contributions from shear and buoyancy production, the turbulent kinetic energy grows as cold front approaches. This energy reaches maximum value after front passage at a level above the building roof, supporting the development of organized turbulent structures.

The building-induced turbulence structures develop along the

downstream direction and merge with front, resulting in the deformation of cold front. The rising motion of turbulence merges with the upward flow ahead of the front and strength, extending the strong rising flow to near surface. At neighboring areas, sinking motion after front is intensified. They two together interrupt the front and generate an uneven front head compared with the condition when urban buildings are absent. The strong mixing within the front head also reduces the temperature gradient. The transformed flow structures express impacts on the transportation process. Turbulent Heat flux and momentum flux are locally strengthened by sweep and ejection events.

This study identifies the crucial contribution of surface warming induced by rapid urbanization to local temperature increase, thus pointing out the importance of urbanization complexity inherent in rapid growth in urban climate change over eastern China. These results provide a new view, which focuses on the rapid growth of urban, for evaluations of urban effects on local climate. Our high-resolution experiments focus on the turbulence in urban areas successfully extend previous street-scale investigations to city-scale studies and provide an example for studying urban boundary layer turbulence with real meso-scale weather and surface description. The results of our urban-scale building-resolving simulation reveal the possibility that cold front may be regulated dramatically after passing by an urban surface. The deformation of cold front is accomplished through the interaction between building-induced turbulence and front. Our results highlight that urban buildings may have significant impacts in regulating local weather.

論文審査の結果の要旨

都市の存在はその熱的，力学的な効果により，局地的な気象や気候に大きな影響を及ぼす。本研究の目的は，中国東部の都市を対象として，熱的な効果である都市の急速な成長と昇温，力学的な効果である寒冷前線通過時の都市における乱流とそのメソスケール現象との相互作用を明らかにすることである。

まず，人工衛星による夜間光のデータを用い，急速な都市成長の効果を有効半径という新しいパラメータを導入して定量的に評価し，長期的な昇温との関係を調べた。著しい都市の昇温は主に急速に都市域が拡大している都市で見られ，都市の昇温率は都市規模および有効半径とともに増大することを示した。この関係は中国東部のうちの中央部，南部，北西部で明瞭であったが，北東部でははっきりしなかった。

次に都市スケールでの高解像度数値シミュレーションを行い，寒冷前線の通過時の都市域における乱流構造と前線との相互作用を解明した。従来の高解像度シミュレーションは街区スケールがほとんどであったが，中国の広州市を対象とした都市スケールでの個別のビルを表現できる水平解像度 10 m のシミュレーションを実施した。その結果として，都市の建物による乱流の生成と組織的な３次元構造が克明に示された。さらに，乱流により寒冷前線が変形され，不均質な構造となることを明らかにした。これらの成果は，これまでほとんど明らかになっていなかった都市の乱流とメソスケール現象の相互作用の一端を解き明かしたものである。

本論文は，都市化と都市の気象・気候に関わる斬新な知見を提示するものであり，本人が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。したがって，朱心悦提出の博士論文は，博士（理学）の学位論文として合格と認める。